의학석사 학위논문

자기공명영상의 T2 mapping을 이용한 무증상 젊은 성인의 견관절 연골 생리의 평가에 관한 실행 가능성 연구

T2 Mapping of Articular Cartilage of the Glenohumeral Joint at 3.0T in Healthy Subjects – A Feasibility Study

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강 유 선

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The Department of Radiology,

Seoul National University

College of Medicine

Yusuhn Kang

ABSTRACT

Introduction: To evaluate the feasibility of quantitative T2 mapping of the glenohumeral joint cartilage at 3.0T and to assess the T2 mapping characteristics of the normal glenohumeral joint.

Materials and Methods: This prospective study was approved by our institutional review board and written informed consent was obtained. Fifteen healthy volunteers were enrolled and underwent a multiecho spin-echo T2-weighted MR imaging of the shoulder and T2 mapping was acquired with a dedicated software. Regions of interest that covered the full thickness of the humeral cartilage and glenoid cartilage were respectively placed on an oblique coronal image to assess the mean T2 relaxation time. T2 profiles of humeral cartilage were measured from the cartilage-bone interface to the articular surface. Intraobserver agreement was analyzed using intraclass correlation coefficient (ICC).

Results: T2 maps were successfully obtained in 13 subjects (mean age, 28.6 years; age range, 24-33 years). All 13 joints showed normal appearance on conventional T2-weighted images, without signal intensity alterations or cartilage defects. On quantitative evaluation, the mean cartilage T2 values of humeral cartilage and glenoid cartilage were 50.5 msec ± 12.1 and 49.0 msec

± 9.9, respectively. Intraobserver agreement was good, as determined by an ICC of 0.736. Longer T2 values were observed at the articular surface with a tendency to decrease toward the bone-cartilage interface. The mean cartilage T2 value was 69.03 msec ± 21.2 at the articular surface and 46.99 msec ± 19.6 at the bone-cartilage interface of the humeral head.

Conclusion: T2 mapping of the glenohumeral joint is feasible on a 3T scanner in a clinically feasible time frame. The T2 profile of the normal humeral cartilage shows a spatial variation with an increase in T2 values from the subchondral bone to the articular surface.

Keywords: Magnetic resonance imaging (MRI)

T2 mapping

Glenohumeral joint

Cartilage

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articular surface and at the bone-cartilage interface.

Figure 4. T2 profiles of the humeral cartilage, as a function of normalized distance from articular surface (0.0) to bone-cartilage interface (1.0). Cartilage T2 shows a tendency to increase toward the articular surface.

INTRODUCTION

The glenohumeral joint is a non-weight-bearing joint, and therefore, less prone to osteoarthritis, compared to weight-bearing joints, such as the knee and hip. However, osteoarthritis of the glenohumeral joint may be a source of significant pain and disability (1). Early degenerative changes of the glenohumeral joint may simulate symptoms of shoulder impingement (2) and glenohumeral articular cartilage changes have been reported to show strong correlations with rotator cuff tears (3). Therefore, the integrity of the cartilage surface of the glenohumeral joint has an influence on the differential diagnosis of shoulder pain and on the treatment plan (2, 4).

The diagnostic performance of various MR sequences and MR arthrography in the evaluation of glenohumeral cartilage lesion has been assessed by several studies (4, 5). Current clinical MRI evaluation of the articular cartilage relies primarily on the identification of morphologic changes in damaged cartilage (6, 7). Morphological degeneration of the cartilage is the end result of a series of events and is known to be preceded by biochemical changes in the cartilage.

Advances in MR imaging techniques of the articular cartilage during the past decade or so, including T1ρ (T1 relaxation time in rotating frame) and T2

relaxation time quantification and delayed gadolinium-enhanced MR imaging of cartilage, have led to the imaging of biophysical properties of the cartilage. Among them, T2 relaxation time mapping has gathered attention as a tool to depict cartilage matrix changes with great potential to provide early detection of cartilage degeneration.

Thus far, T2 mapping has been limited mainly to the articular cartilage of the knee (8-11), with sparse studies involving the interphalangeal joints (12, 13) and ankle joints (14). To our knowledge, T2 mapping of the glenohumeral joint has been reported by only one study by Maizlin et al (15). However their study was limited to qualitative assessment of the T2 maps without quantitative data.

The purpose of this study was to evaluate the feasibility of quantitative T2 mapping of the glenohumeral joint cartilage at 3.0T, and to assess the T2 mapping characteristics of the normal glenohumeral joint.

MATERIALS AND METHODS

This prospective study was approved by our institutional review board, and written informed consent was obtained from all subjects prior to enrollment.

Patient selection

From December 2012 through July 2013, we prospectively enrolled healthy volunteers if they met the following inclusion criteria: (a) age 18-40 years, (b) the absence of pain, limitation of motion or other symptoms in the shoulder joint, (c) no history of trauma or orthopedic surgery. Subjects with contraindication to MR imaging were excluded. A total of 15 subjects (mean age, 29.1 years; age range, 24-37 years), including nine men and six women, were enrolled in the study

MR T2 mapping

All MR images were obtained with a 3T MR imager (Intera Achieva, Philips Medical Systems, Amsterdam, the Netherlands). The imaging sequence consisted of an oblique-coronal, multiecho spin-echo T2-weighted sequence performed with the following imaging parameters: repetition time msec/echo time msec, 3500/13, 26, 39, 52, 65, 78 and 91; field of view, 140 x

140 mm; pixel matrix, 232 x 175; bandwidth, 217 Hz/pixel; 10 sections; a 3mm section thickness; one acquired signal; total acquisition time, 5minutes 18 seconds. Images were reconstructed to a 400 x 400 matrix, with a resulting in-plane pixel resulting of 350㎛. The range of echo times are similar to previous studies (11, 13, 15).

Quantitative T2 maps were calculated using RelaxMaps tool V 2.1.1 (PRIDE Software, Philips Healthcare) from the oblique coronal data sets obtained through the glenohumeral joint. The T2 maps were generated with a mono-exponential curve fit. The T2 maps were color-coded from 0ms to 250ms on a pixel-by-pixel basis, with red denoting 250ms, and violet 1ms.

Image analysis

Conventional T2-weighted oblique-coronal images were first qualitatively evaluated for cartilage lesions of the humeral head and glenoid. MR images were considered positive for a cartilage lesion if the cartilage showed signal intensity alterations, irregular surface contour or cartilage defects.

T2 maps were also qualitatively assessed for any focal alterations in the T2 values, based on the color spectrum. For quantitative analysis of the T2 maps, the section containing the largest area of cartilage was chosen from the ten consecutive sections. The mean T2 relaxation time was measured by placing a

free-hand region of interest (ROI) over the humeral and glenoid cartilage on the T2 maps with reference to the conventional T2-weighted images. ROIs were carefully placed so that they encompassed the whole thickness of the cartilage (Fig. 1). To assess the intraobserver variability, measurements were taken in two separate sessions, more than two weeks apart. In the first session, the measurement was repeated three times and the average value was used for overall analysis. The T2 profile of humeral cartilage was assessed by sampling the pixel values along a line perpendicular to the cartilage surface, at the point of maximum cartilage thickness (Fig. 2). Six pixel values were sampled from the articular surface to the bone-cartilage interface.

Statistical Analysis

Data were analyzed with the SPSS statistical software package (SPSS for Windows, version 18.0; SPSS, Chicago, Ill). The results were expressed as mean ± standard deviation. Intraobserver agreement was assessed by using intraclass correlation coefficients (ICCs) calculated with the one-way random-effects model. An ICC of less than 0.40 signified poor agreement; an ICC of 0.40–0.75, fair to good (moderate) agreement; and an ICC of 0.76–1.00, excellent agreement (16) .

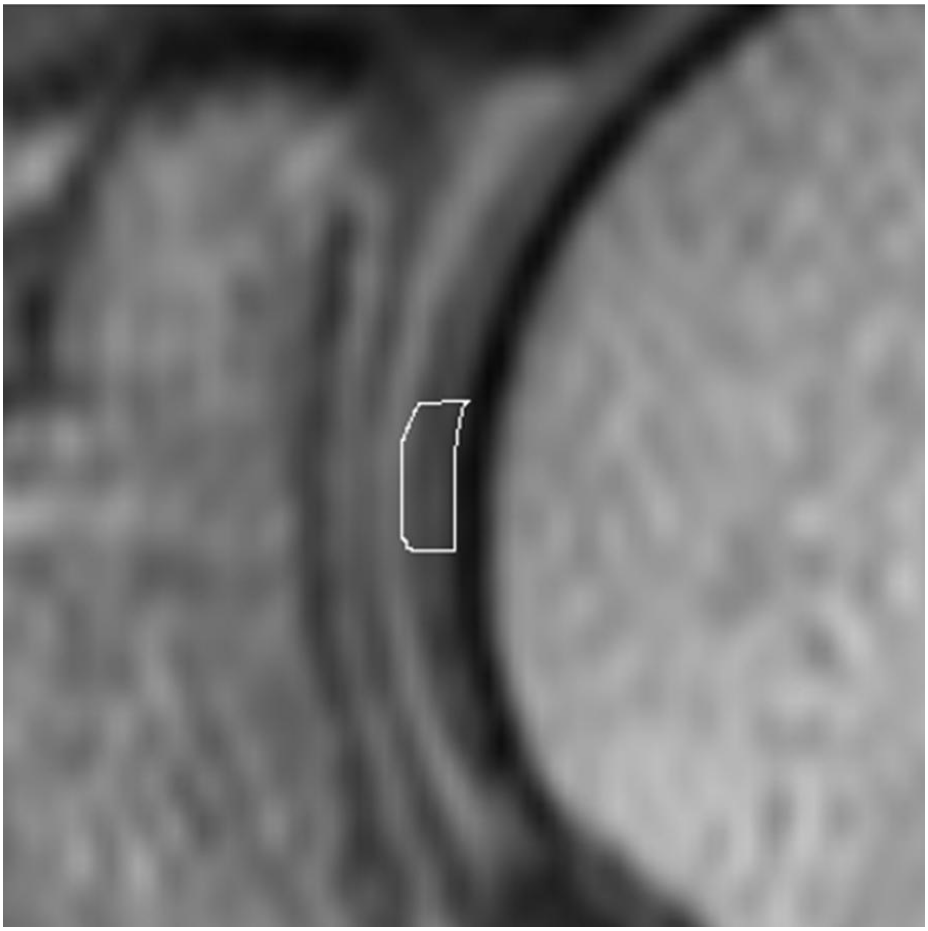

Fig. 1a

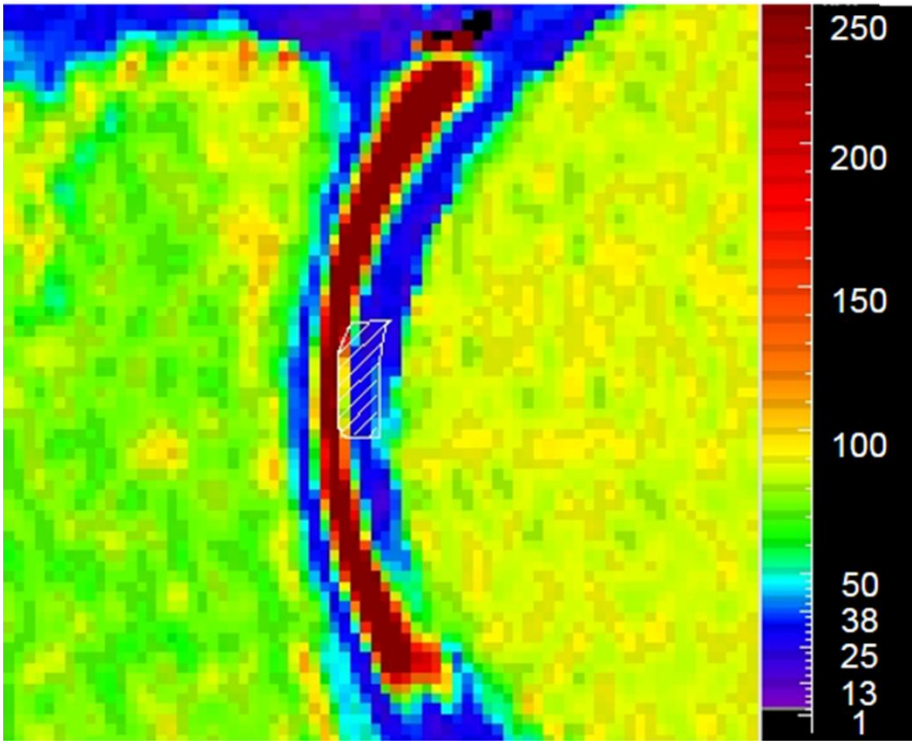

Fig. 1b

Figure 1. A free-hand region of interest (ROI) is placed over the humeral cartilage on the T2 maps (b) with reference to the conventional T2-weighted images (a). The ROI are carefully placed so that they encompass the whole thickness of the humeral cartilage

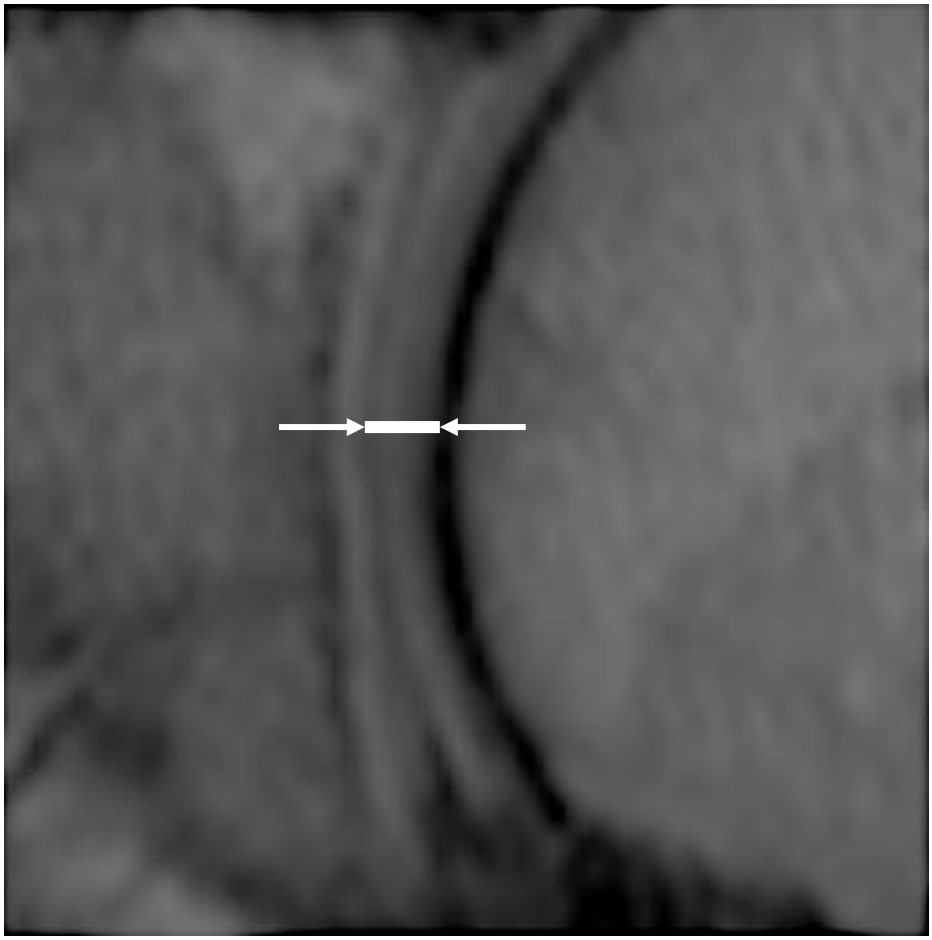

Fig. 2

Figure 2. The T2 profile of humeral cartilage was assessed by sampling the pixel values along a line perpendicular to the cartilage surface, at the point of maximum cartilage thickness.

RESULTS

Out of fifteen subjects, two subjects had conventional MR images and T2 maps of inadequate quality for analysis due to marked chemical shift artifact at the bone-cartilage interface and were excluded from final analysis. T2 maps were successfully obtained in 13 subjects (mean age, 28.6 years; age range, 24-33 years).

All 13 joints showed normal appearance on conventional T2-weighted images, without signal intensity alterations or cartilage defects. The color display of the T2 maps provided an efficient visual assessment of T2 relaxation time and its distribution pattern. The T2 value of the cartilage showed a zonal variation with slightly longer values in the superficial layer than in the deep layer. Representative T2-weighted images and T2 maps of the glenohumeral joint are shown in Figure 3.

On quantitative evaluation, the mean cartilage T2 value of humeral cartilage and glenoid cartilage were 50.5 msec ± 12.1 and 49.0 msec ± 9.9, respectively. Intraobserver agreement was good, as determined by an ICC of 0.736. Individual T2 profiles of the 13 subjects are shown in Figure 4. As noted in

the visual assessment of the T2 maps, longer T2 values are observed at the articular surface with a tendency to decrease toward the bone-cartilage interface. In addition a slight rise of T2 value was observed at the bone-cartilage surface. The mean cartilage T2 value was 69.03 msec ± 21.2 at the articular surface and 46.99 msec ± 19.6 at the bone-cartilage interface of humeral head.

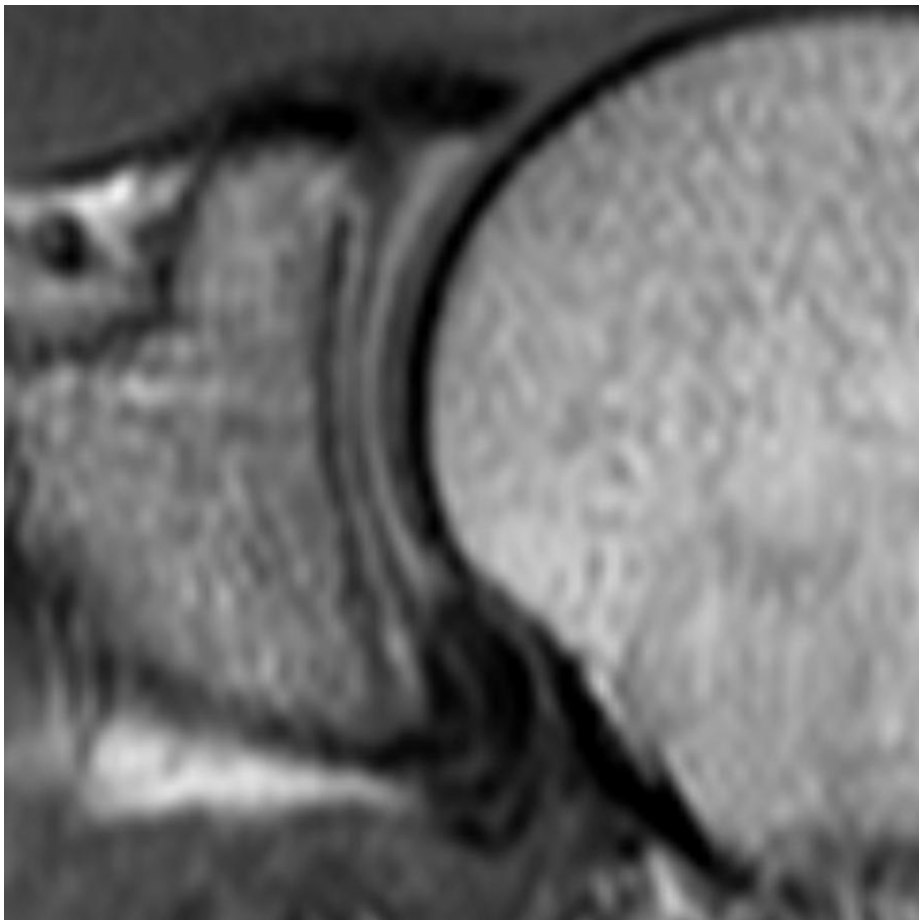

Fig. 3a

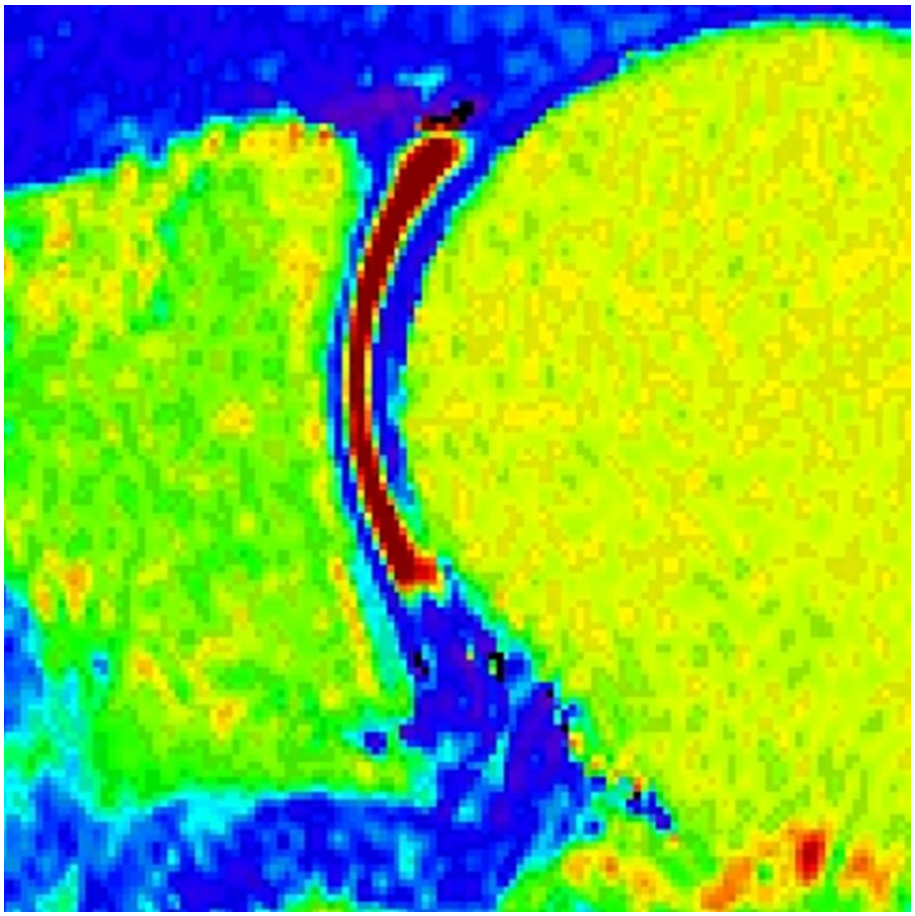

Fig. 3b

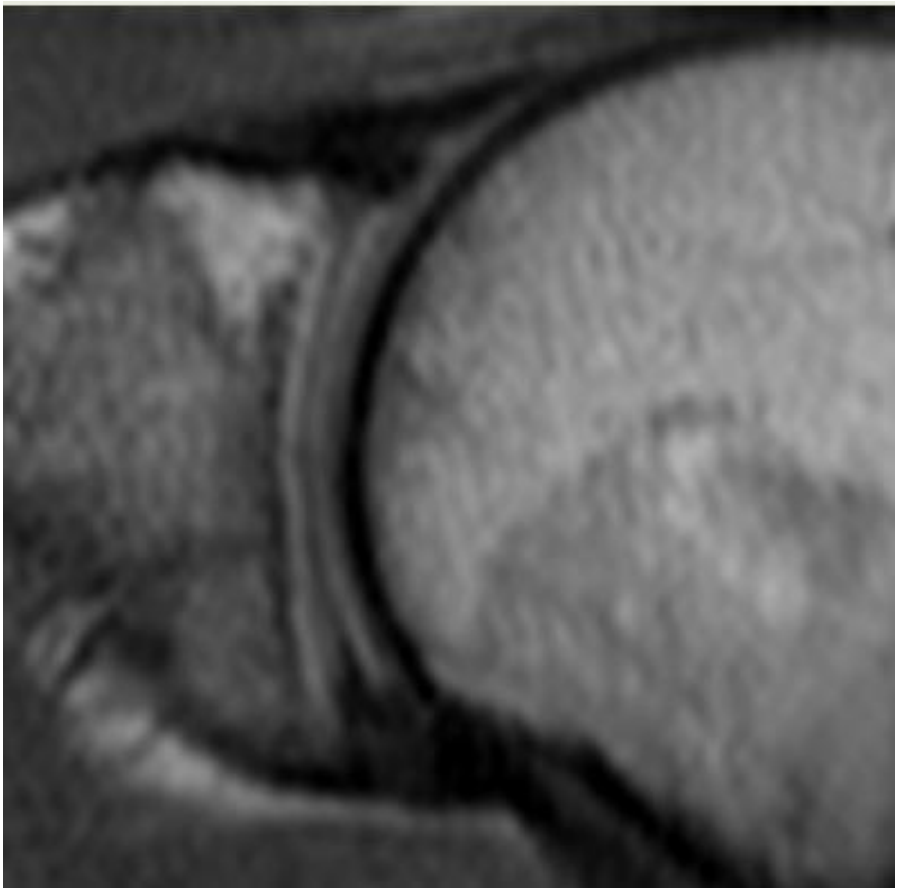

Fig. 3c

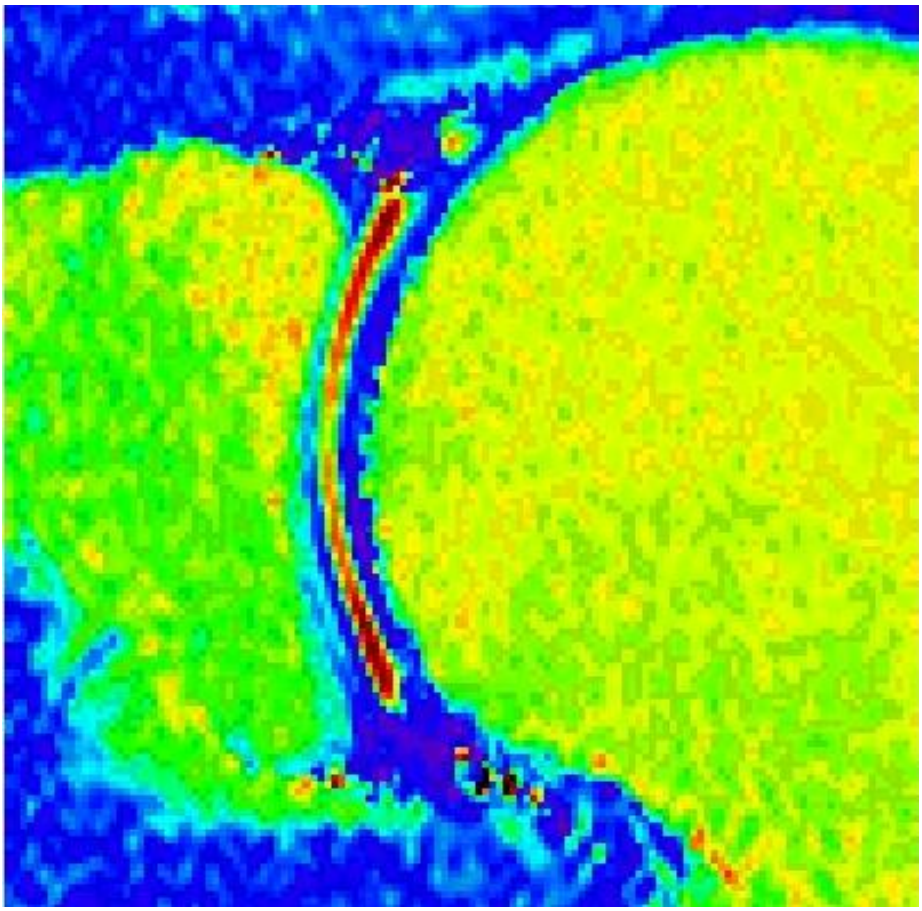

Fig. 3d

Figure 3. Representative coronal MR T2-weighted images (a, c) and T2 maps (b, d) of the glenohumeral joint of asymptomatic young adults. Images were reconstructed with an in-plane pixel resolution of 350㎛. There is spatial variation in cartilage T2, with values increasing at the articular surface.

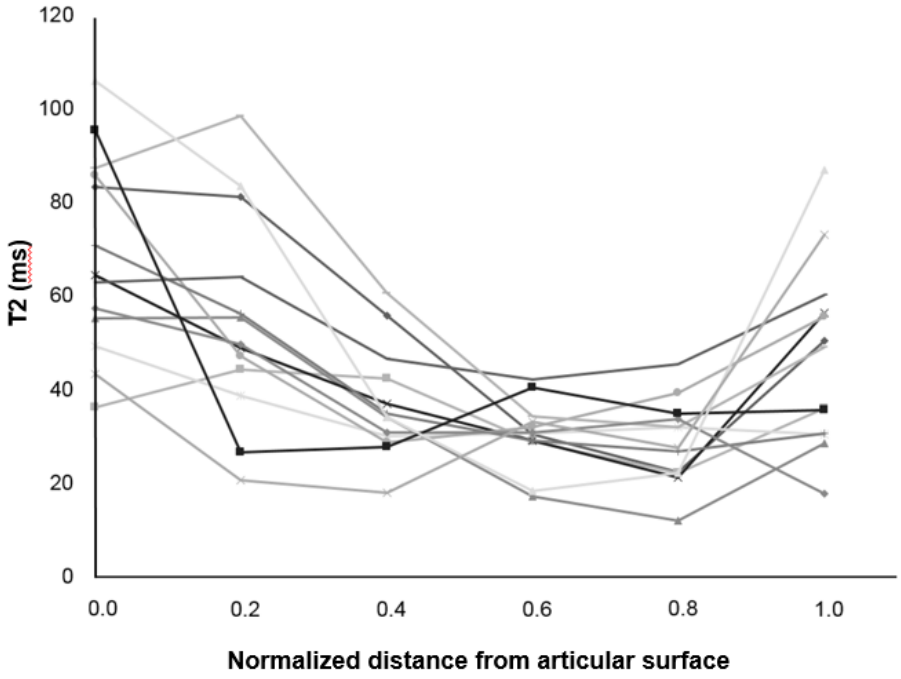

Fig. 4

Figure 4. T2 profiles of the humeral cartilage, as a function of normalized distance from articular surface (0.0) to bone-cartilage interface (1.0). Longer T2 values are observed at the articular surface with a tendency to decrease toward the bone-cartilage interface. In addition, the T2 profiles show a brief increase of T2 at the bone-cartilage interface

DISCUSSION

Advances in MR imaging have led to parametric mapping techniques, such as delayed gadolinium-enhanced MR imaging of cartilage (dGEMRIC), T1ρ and T2 mapping of the cartilage. T1ρ mapping and dGEMRIC reflects the proteoglycan and glycosaminoglycan contents of the articular cartilage, respectively, whereas T2 relaxation time is a sensitive parameter for the evaluation of changes in water and collagen content and tissue anisotropy of the articular cartilage (7). These parametric MR imaging techniques visualize the biochemical and biophysical changes of articular cartilage which are known to precede morphologic changes. Therefore, these techniques may serve as early indicators of articular cartilage damage or degeneration, and furthermore, may enable diagnosis and treatment of cartilage lesions at an earlier stage.

Thus far, the application of T2 mapping in the glenohumeral joint has been limited due to its thin and curved cartilage. A study by Maizlin et al (15) demonstrated the correlation of T2 maps of articular cartilage of the glenohumeral joint with findings at conventional MR imaging. In addition the normal T2 maps of hyaline cartilage demonstrated a layered appearance with

different color spectra in the superficial and deeper layers of the cartilage in their study. However, their study was limited to a qualitative analysis of the T2 maps of the glenohumeral joint. To our best knowledge, our study is the first to demonstrate the feasibility of quantitative cartilage T2 mapping of the glenohumeral joints.

The mean T2 values of the humeral head and glenoid cartilage were respectively, 50.5 msec ± 12.1 and 49.0 msec ± 9.9 in our study. These values are similar to quantitative T2 values reported in the femoral cartilage (50.2 msec ± 8.4) (11) and talus (54.2 ± 6.9 msec) (14). Cartilage has been reported to have short T2 values that range from 20 to 60 msec (13). The short T2 value of cartilage, despite its high water content, results from the limited mobility of water molecules within a highly anistropic matrix (7). The three-dimensional organization of the collagen network limits water mobility and this causes magic angle effect, influencing the T2 signal intensity of cartilage (17).

The T2 values of the humeral cartilage showed a spatial variation with longer T2 values observed at the articular surface with a tendency to decrease toward the bone-cartilage interface. This result is comparable to other studies

which have reported increasing T2 values toward the articular surface in the patellar cartilage (9, 18). Mosher et al (18) reported a spatial dependency in T2 of the patella cartilage, increasing from 30msec near the subchondral bone to approximately 65msec near the articular surface. The range of spatial variation was from 47 msec at the bone-cartilage interface to 69 msec at the articular surface in our study. These values are similar to that of patellar cartilage (45 - 67msec) and femoral cartilage (46 - 56 msec) reported by Smith et al (19). The spatial variation is thought to result from regional differences in the extracellular matrix, the dominant factor being tissue anisotropy characterized by collagen matrix orientation (7); radial configuration of the collagen fibers that are perpendicular at the cartilage-bone interface and parallel at the superficial layer (12). In five cases of our study, the T2 value of the articular surface exceeded 80 msec. The high T2 value cannot be explained solely by the difference in collagen matrix orientation, and we speculate that it may have partly resulted from volume averaging of cartilage with synovial fluid.

In addition, the T2 profiles of the humeral cartilage showed prolonged T2 relaxation time near the bone-cartilage interface, in the present study. These results were in concordance with those of previous studies in the knee and

interphalangeal joint cartilage (13, 19). In a study of bovine cartilage, Nieminen et al (20) showed that the zone of high T2 value at bone-cartilage interface corresponded to a zone of cartilage that contained an accumulation of chondrocytes. Other possible explanations for the area of prolonged T2 relaxation time is artifact from volume averaging of cartilage with the bone and chemical shift artifact from fatty marrow contaminating the T2 measurement of articular cartilage (19). The determination of bone-cartilage interface was challenging in some cases due to the aforementioned artifacts.

There are some limitations to our study. First, the number of subjects included in the study was relatively small, limiting statistical analysis and generalization of the results. Second, the cartilage findings were not confirmed with arthroscopy or histologically. However, it would be unethical to perform arthroscopy on these young, healthy volunteers without should symptoms. Third, the pixel resolution was relatively low, considering the thickness of the humeral cartilage. The in-plane pixel resolution of the images was 350㎛ in this study. Cartilage T2 maps with an in-plane resolution of 332㎛ have been used in the evaluation of in vivo femoral/tibial cartilage and 547㎛ for patellar cartilage (19). At this pixel resolution, it is possible to obtain spatially resolved cartilage T2 maps with approximately 7 to 8 pixels

across the thickness of the cartilage, assuming the approximate thickness of the cartilage to be 2.5mm and 4.5mm for the femoral/tibial cartilage and patellar cartilage, respectively. The thickness of the humeral head cartilage measured on cadevaric specimens was 1.24 ± 0.50 mm (21). Considering this fact, the in-plane pixel resolution should be around 150㎛ to obtain comparable T2 maps. Further investigations with higher resolution is warranted for elaborate assessment of the glenohumeral joint cartilage. Lastly, intra- or interobserver agreement was not obtained. However, the strength of our study is that T2 maps could be acquired in the clinically feasible time frame using a clinical MR scanner and we were able to suggest a possible normal range for cartilage T2 values of the glenohumeral joint in young, healthy volunteers.

In conclusion, the results of the present study demonstrate the feasibility of performing quantitative in vivo T2 mapping of the glenohumeral joint in a clinically feasible time frame. The T2 profile of the normal humeral cartilage shows a spatial variation with an increase in the T2 values from the subchondral bone to the articular surface.

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국문초록

목적: 무증상 젊은 성인의 정상 견관절 연골을 3.0 테슬라 자기공명영상의 T2 mapping을 이용하여 영상화할 수 있는지 그 실행가능성을 검증하고, 정상 견관절 연골의 T2 mapping 소견을 알아보고자 한다.

대상과 방법: 전향적으로 수집한 15명의 건강한 무증상의 성인에서 3.0 테슬라 자기공명영상 장치를 이용하여 어깨관절의 자기공명영상을 획득하였다. 자기공명영상에는 다중 에코 스핀에코 T2 강조영상을 포함하였으며, software를 이용하여 획득된 영상으로부터 T2 map을 얻었다. 견관절의 사위 관상면 영상에서 상완골두의 관절연골이 가장 두껍게 보이는 단면을 선택한 후에 상완골두의 관절 연골에 관심 영역을 설정하여 평균 T2 이완 시간을 측정하였다. 관절연골의 표면에서부터 뼈와 연골의 경계에 이르기 까지 T2 이완 시간의 공간적 변화 양상을 알아보았다.

결과: 13명의 무증상 성인 (평균나이, 28.6세; 나이 범주, 24-33세)에서 T2 map 을 성공적으로 획득하였다. 13예 모두 고전적인 T2 강조영상에서 신호강도의 이상이나 연골표면의 이상 없이 정상 소견을 보였다. 정량적인 분석에서, 상완골두 연골의 평균 T2 이완시

간은 50.5 msec ± 12.1으로 측정되었다. 관절연골의 표면에서부터 뼈와 연골의 경계로 갈수록 T2 이완 시간은 전반적으로 감소하는 추세를 보였으며 뼈와 연골의 경계에서는 약간의 상승을 보였다. 관절연골의 표면에서는 연골의 평균 T2 이완시간이 69.03 msec ± 21.2 이었으며, 뼈와 연골의 경계에서는 46.99 msec ± 19.6 로 측정되었다.

결론: 견관절의 T2 mapping은 3 테슬라 자기공명영상 장치에서 실행 가능하며, 정상 견관절의 상완골두 연골은 관절연골의 표면에서부터 뼈와 연골의 경계로 갈수록 T2 이완 시간이 감소하는 공간적인 변화 양상을 보인다.

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주요어: 자기공명영상, T2 mapping, 견관절, 관절연골

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